# Solutions for Beam Stripping at RIA

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## 1. Beam stripping at RIA

The current concept for the RIA accelerator complex foresees four beam-stripping positions. Two of these will be in the driver accelerator and two in the post-acceleration of radioactive ion beams [1, 2]. The RIA Driver Linac design is optimized for accelerating high power uranium beams starting from an ECR ion source at charge state 29. To keep the total accelerating voltage relatively low (1.4 GeV) two stripping stages are assumed, the first at ~10.5 MeV/u and the second at ~80 MeV/u for uranium ions. For the final design goal of 400 kW of uranium beam at 400 MeV/u, the beam current at the first stripper location will be ~ 5 particle μA. In the post-acceleration scheme a $1^+$ radioactive ion beam exits a conventional ion source or a gas catcher/ ion guide system. Predicted maximum currents are normally limited by space charge effects in the gas catcher to $10^9$ ions/s, but in those cases where traditional ISOL sources can be used ion currents up to $10^{12}$ 1/s are predicted [3]. The current proposal accelerates the beam to a first stripping stage at about 10-30 keV/u using RFQ's. Further acceleration with a linac leads to a second stripping at about 600 keV/u, before further linacs accelerate to the energies requested by the users. In all stripping stages, the use of solid (there is no data for liquid) materials is preferred compared to gaseous materials, as a multitude of measurements [4] show that solid strippers achieve the higher average charge state distribution, which leads to more cost effective acceleration schemes. In order to keep energy and angle straggling low, low Z materials, just thick enough to achieve charge state equilibrium, are preferred. They also lead in most energy regimes to higher average equilibrium charge states. In those cases where high beam currents or low beam energies make solid stripper solutions impossible, extended gas or gas jet targets can be and are used [5].

## 2. Stripper options for current RIA plan

Usually employed for ion beam stripping to higher charge states are foil strippers out of carbon. They have the advantage of being inexpensive and thermally strong due to the high melting point of the material. Carbon has the further advantage of being a low Z material resulting in smaller angle and energy straggling compared to higher Z materials. In many energy regimes lower Z materials also lead to higher average charge state distributions [6]. In the area around the stopping power maximum, carbon foils have been used as target backing for experiments at GSI searching for super heavy elements with incident ion beam currents up to 0.5 pμA of 5 MeV/u Nickel ions [7]. In order to achieve reasonable target lifetimes, several foils are here mounted on a target wheel, which is rotating with an angular velocity adjusted to the duty cycle of the Unilac. From the current data on the benchmark Uranium beam it is not clear if a foil stripper could withstand the necessary 5 pμA beam current at 10.5 MeV/u which is still near the area of the stopping power maximum. At higher beam energies (~ 80 MeV/u) in the driver the deposited energy is lower by about a factor 2 and with the reduction in beam current compared to the first stripping position the problem will be smaller. Nevertheless, the deposited beam power will still be roughly a factor 10 larger than experienced so far at SHIP/GSI. There is also no available data on energy and angle straggling of these heavy ions in the stripping material at RIA energies. This information is vital for the further development of the RIA acceleration concept as all planned acceleration stages depend on achieving certain charge states in the stripping processes.

An attractive alternative in principle is given by extended gas or gas jet stripper sections. Gas targets are stable, virtually indestructible and, once set up, easy to maintain. The disadvantage is given by the lower average charge state distribution of ions exciting gas compared to solid strippers [4]. Another limitation is that, while they can be made as thin as necessary, there are limitations to the practical maximum thickness that is useful. In extended gas targets thinning effects due to gas heating appear with the amount of beam power exceeding about 20 mW/mm [9], thus limiting the useful gas pressure in the stripper volume. This effect does not appear in gas jet strippers as the fast flow of gas (supersonic) minimizes the deposit of beam power in a given gas volume. Due to the high throughput of gas in gas jets, these strippers would also be limited in gas density by the capability to recirculate and compress the gas. If the use of gas targets would become unavoidable in the driver, the use of heavier gases would be necessary, but the accelerator concept would have to be modified for the lower charge states expected from the gas stripping process. One gas stripper is nevertheless foreseen in the RIA post-acceleration. A thin extended Helium target will here strip 10 – 30 keV/u ions coming from the RFQ stages for further acceleration in linacs. Initial tests at Argonne have shown the viability of this concept [10]. Also with gas strippers very little information is available on energy and angle straggling. As a third alternative, Argonne National Laboratory has started the development of liquid Lithium strippers, which resulted in first successes for about 1 cm thick material [11]. As this is a completely new concept, nothing is known about equilibrium charge states, equilibrium thickness, straggling etc. of heavy ions in this liquid stripper material. It is also not yet known how thin a stream of liquid Lithium can be obtained, that is for which stripper positions this type will become available. At the 10.5 MeV/u position in the RIA driver a thickness of about 10 μm would be needed.

Generally, for all discussed stripper solutions equilibrium thickness needs to be determined at the beam energies of interest for RIA, as the thickness of the stripper materials (solid, liquid or gaseous) has to be kept to a minimum to also minimize straggling processes. These might affect beam quality and transport efficiencies.

## 3. Current status of our development work

With receipt of the first funds we started this summer with this research project. The current status in our three part projects is described below.

### a) Short Helium gas stripper

We have started the design study (Fig. 1) on a short Helium or Hydrogen gas stripper system to be used as a first stripper in the RIA post-acceleration. At this position in the RIA system the radioactive ions will be very slow and the beam size might require apertures in the gas stripper larger than 1 cm diameter. In close collaboration with the accelerator design at Argonne National Laboratory we have defined the specifications for the gas stripper and performed the necessary gas flow calculations.

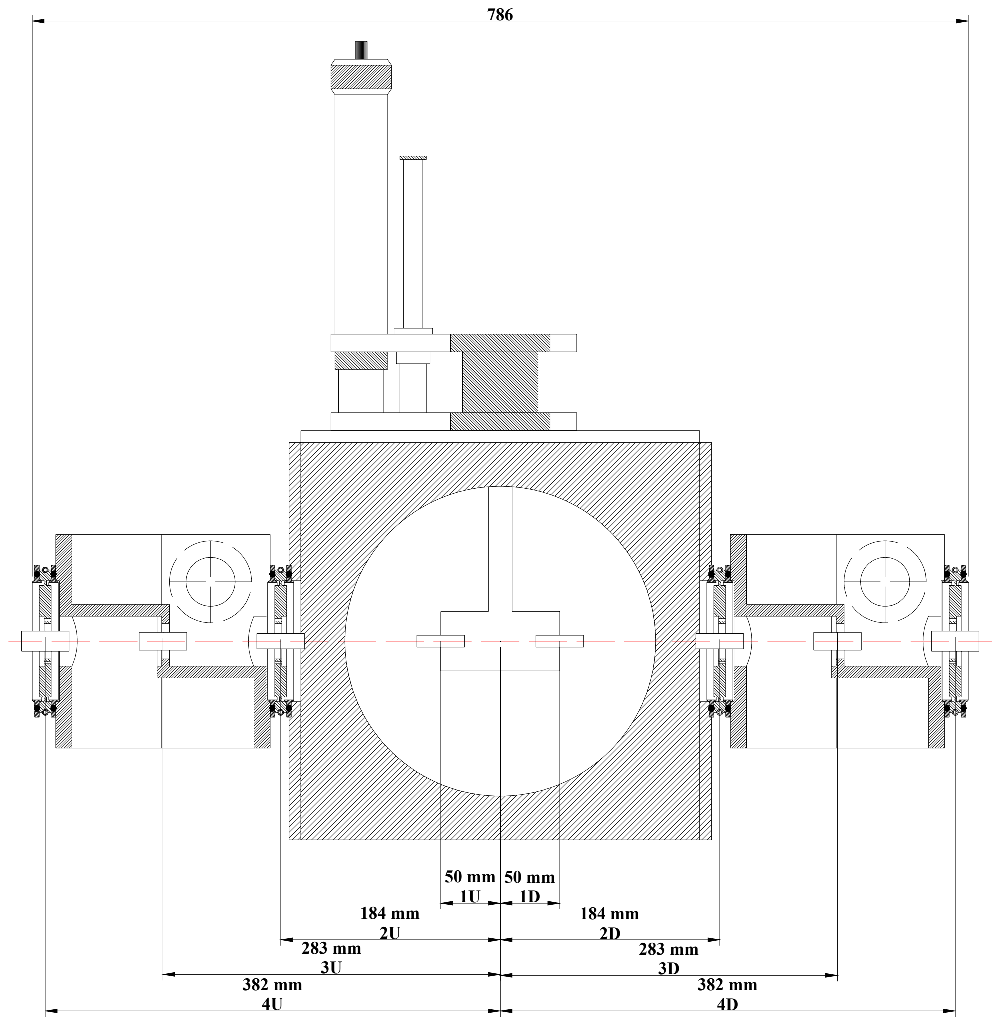


Fig. 1: Overview drawing of the RIA gas stripper section

We will soon have the have the design completed. At this point we will apply in collaboration with Argonne National Laboratory for the funds to build the gas stripper and test it at Argonne's Dynamitron accelerator. These tests will concentrate on energy and angle straggling as well as the determination of equilibrium thickness of the high Z beams in Helium and Hydrogen, where, for these slow velocities, very little data exists and current semi-empirical codes are unreliable. The results from these measurements will have to be fed back into beam transport calculations and eventually into RIA accelerator design.

b) Gas cooled Carbon foil stripper

As mentioned above, the deposited beam power in the stripping foils will be a factor 10-20 higher than experienced so far at other accelerator facilities. A simple estimate shows that even with liquid nitrogen cooled shields around the stripper wheel, in the best case only 1/3 of the deposited power could be radiated away. Dealing with a similar problem, the SHIP group at GSI was proposing to try to counter a factor 2 higher beam current on their target wheel by introducing a gas cooling of the target foils [8].

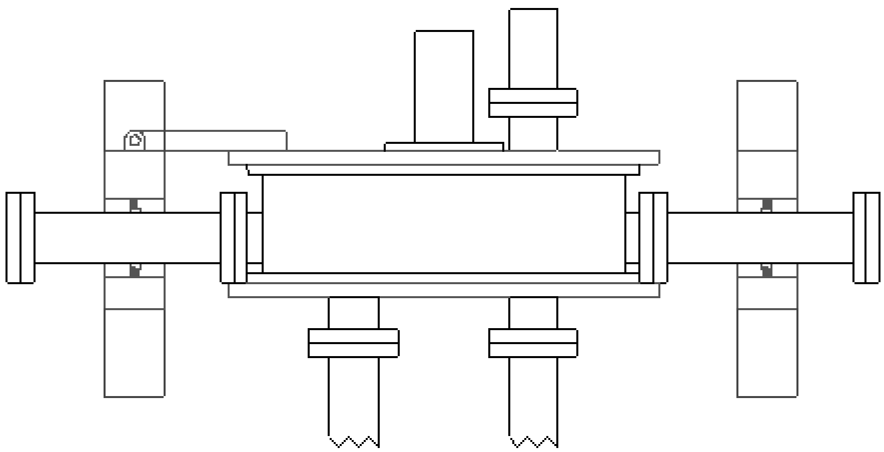

Fig. 2 Conceptual drawing of stripper wheel test setup.

We are currently designing a simple stripper wheel test setup (Fig. 2) with Helium gas cooling and want to test the general concept first without ion beams in our laboratory at the Colorado School of Mines. If it proves to be feasible we will test it with intense Hydrogen or Helium beams at the Argonne Dynamitron. These intense light ion beams at about 100 μA beam current and energies around 1MeV will deposit similar beam power in the foils as a pμA Uranium beam at 10.5 MeV/u or 80 MeV/u and thus should provide a good endurance test. We hope that this stripper solution will provide a viable alternative if a liquid Lithium solution is not achievable or not attractive after tests of stripping efficiencies.

c) Equilibrium charge state, equilibrium thickness and straggling measurements at RIA energies

For parameters like equilibrium charge states, equilibrium thickness and straggling very little or no information exists at the beam energies relevant for the RIA acceleration scheme. Even at other energies, data is too spotty to be readily extrapolated [4, 6].

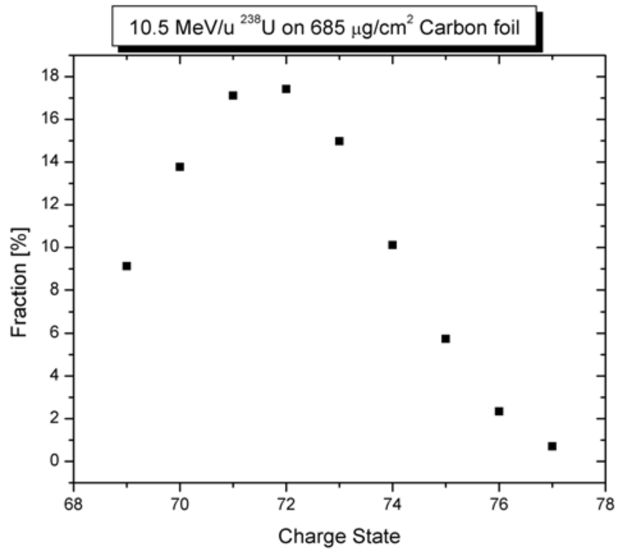


Fig. 3: Charge state distribution of 238-U at 10.5 MeV/u after 685 mg/cm2 Carbon foil.

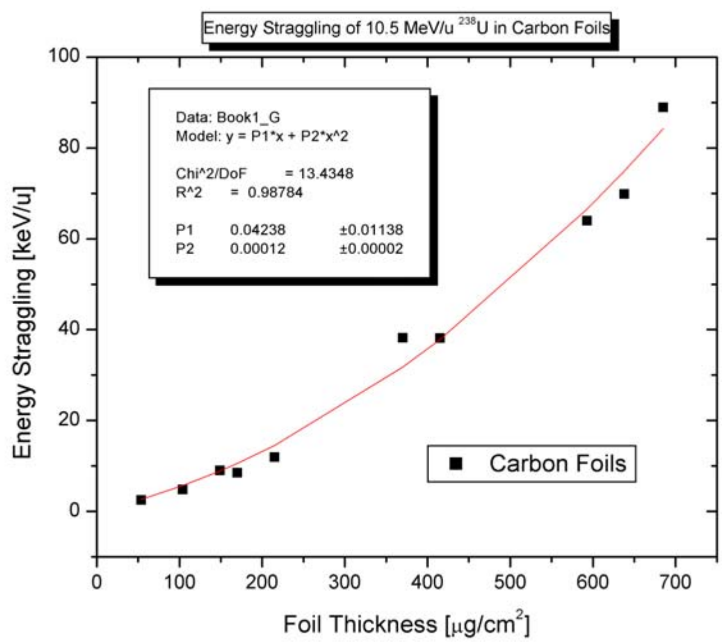


Fig. 4: Energy straggling of 238-U at 10.5 MeV/u in Carbon foils of different thickness.

Initial measurements were performed at the Texas A&M cyclotron facility with 10.5 MeV/u 238-U beam before we joined into this project. The analysis of the data was started by our group and some preliminary results exist on charge state distributions and straggling (Fig 3 and 4).

4. Bibliography

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